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PREFACE TO REISSUE
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Since the publication of this study in 1943 the conclusions have been amply substantiated by continued work in this laboratory and by other experimenters[1,2,3,4]. It is now accepted that diagnoses made with pseudo-isochromatic plates are invalid unless the plates are administered under the illuminant for which they were designed.

This study demonstrated that tungsten lighting falsified the tests and that natural daylight varied too widely to be dependable. The recommendation was made that a standard daylight lamp unit should be furnished in conjunction with the book of plates. Such a lamp and bookholder was designed at the Medical Research Laboratory in 1943 and manufactured by the Macbeth Daylighting Corporation[5]. The holder, illustrated below, fits the bindings of all types of standard pseudo-isochromatic plates at the proper angle of illumination and viewing. The correct color quality of the illuminant is provided by the Corning-Macbeth roundel in the lamp housing. Now that a standard lamp is available, only ignorance or carelessness can excuse fallacious administration of tests.

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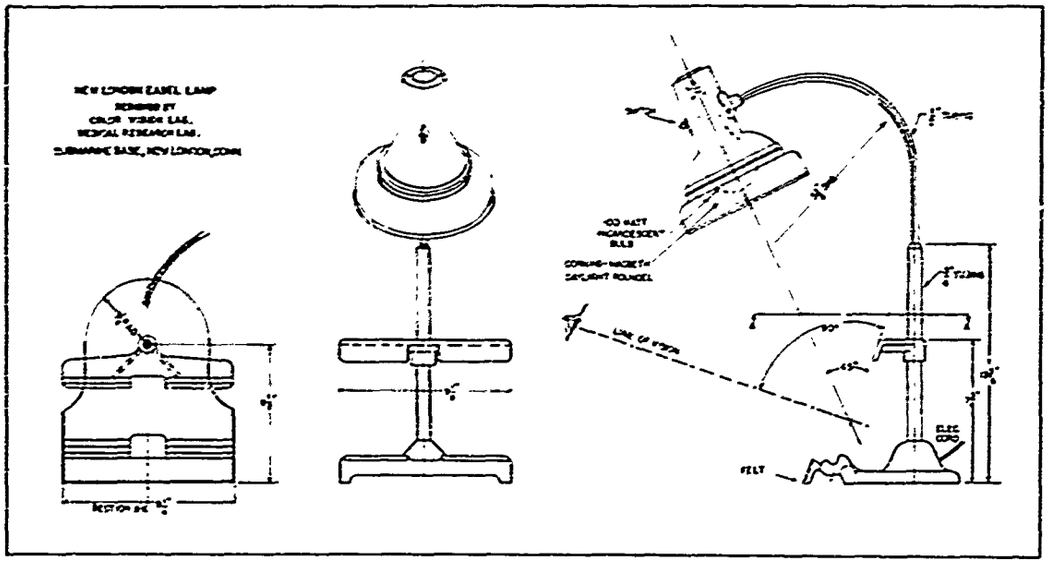

THE EFFECT OF CERTAIN ILLUMINANTS ON SCORES MADE ON PSEUDO-ISOCHROMATIC TESTS

SUMMARY

The selection of pseudo-isochromatic plates and the interpretation of the scores have been decided from studies made under standard illuminants. However, color tests in the Navy are administered under a wide variety of lighting conditions. The color temperature of a number of these illuminants was measured, and two test lights were selected which represented diverse parts of the color-illuminant range: one, yellowish incandescent light, the other, standard mixed daylight. An abridged set of A.O. Plates was given to a test group under these two lights.

Results:

Variations in "natural" daylight were sufficient to account for large differences in the error scores of deuteranomalous observers.

Change from mixed daylight to yellowish incandescent light reduced the total error scores of the deuteranomalous observers by more than half.

Approximately half of the deuteranomalous observers in the test group passed the same test under yellowish illumination which they failed under standard white.

Lesser to no change was found in the protanomalous scores made under the two illuminants.

Conclusions:

Present acceptance-rejection standards are invalid when pseudo-isochromatic plates are administered under non-standard illumination.

The administration of the plates under yellowish light-natural or incandescent--tends to cause rejection of protanomalous and acceptance of deuteranomalous applicants.

Recommendations:

Pseudo-isochromatic plates should be furnished for testing in conjunction with a standard daylight lamp unit.

PROBLEM

Pseudo-isochromatic plates for testing color vision are standardized under average daylight or "Illuminant C" light, Report #3 from the Color Vision Laboratory, U. S. Submarine Base, New London, Connecticut indicated that color vision tests are not generally administered under standardized illumination. With the exception of a brief report on fluorescent lamps from Randolph Field[1], the effect of various illuminants on responses to pseudo-isochromatic plates has not been studied, and no work has been reported on the differential effect of illuminants on protanomalous ("red-blind") and deuteranomalous ("green-blind") types of defective color perception.

The validity of two procedures is involved:

1. The selection of plates for testing. The diagnostic reliability of pseudo-isochromatic plates has been estimated from experiments made under standard illumination and the selected plates are assumed to have the same diagnostic significance for all types of color vision when used as a test. The common use of yellowish illuminants for actual testing has not been taken into account.

2. The establishment of passing and failing criteria. Any pseudo-isochromatic plate is intended to dichotomize a population at some percentage cut-off. On a particular group of plates the error scores which designate the cut-off have been determined from data secured under standard illuminants. What this numerical error score indicates when it is compared with the corresponding score under yellowish incandescent light is unknown.

DISCUSSION

Color Temperature:

The color of a light is commonly described in terms of "Color Temperature", or the point on the Planckian Locus which lies nearest to the position where the illuminant plots on a light mixture diagram. Color temperatures are given in degrees Kelvin (°K) which designate, for our purposes, a purely arbitrary scale related to color but not to actual temperature. Sample temperatures are: blue sky 20,000°K, mixed daylight 6,500°K, incandescent lamps 2,800°K, candlelight 1950°K. The color of illumination in a room or through a window is not the color of the primary light source alone. It is modified by transmission and reflection.

The extent of differences between the colors of common illuminants is almost unbelievable unless, by accident or experiment, the contrasting lights are brought side by side against a neutral background. Because of the psychological response known as "color constancy" variations in illumination color are never fully appreciated. The Eastman Color-Temperature Meter was chosen as the simplest instrument for measuring such light differences.

The Eastman Meter is essentially a two-element colorimeter which measures color temperature in terms of the redness or greenness of the light. The transmission peaks are at 680 mu in the red and at 520 mu in the green. It is therefore a peculiarly reliable measure of the color temperature scale as seen by observers deficient in red or green sensation. The meter has been fully described by Lowry and Weaver[2].

PROCEDURE

A variety of illuminations was measured with the Eastman Color Temperature Meter. Rooms were chosen in the dispensary and in other buildings about the Submarine Base which represented the variety of the conditions under which color tests are known to be given in the Navy, such as north exposure, south exposure, buff walls, grey walls, bare ceiling lights, opal bowls over the lamps, etc.; daytime and night time illumination; reflecting surfaces outside of windows; and changes with time of day and with weather conditions. The test surface was a square of dulled white Bristol board. The meter was calibrated by the same observer who made the room readings.

Figure 1 presents graphically the variations which were found in color of illumination. In Columns 2 and 3 are readings taken in the same rooms but with variations in light conditions and locations within the rooms. In Column 4 are readings taken in two possible testing locations in offices of differing exposure and decoration. Column 5 indicates that the color of natural lighting through windows depends upon the outside objects and conditions and that it ranges from a yellow almost as warm as incandescent light to a blue, much colder than average daylight. It is evident that "natural daylight" is no guarantee of white light; the fact that a light enters through a window does not make it a standard of sufficient invariability for testing purposes.

Choice of Test Lights:

The two standard lights were chosen to represent the upper and lower portions of the color range shown in Fig. 1. Obviously one of the experimental lights should be the average daylight required for standard administration of pseudo-isochromatic tests. A standard daylight lamp with Macbeth-Corning filter provided such a constant source; it will be referred to as "Macbeth C" illuminant. Another experimental test light was a 100 watt lamp with filter chosen to approximate the yellowish illumination of an ordinary office under artificial light; such a room was assumed to have walls painted buff or cream with the light diffused by a standard glass reflector. This light will be referred to as "Room Y" illuminant. The color temperatures of these two lights are indicated by circled crosses in Figure 1, Column 1. It is evident that they do not reproduce the full extremes of illumination which can be found in examining offices and recruiting stations but are representative of what can be considered typical natural and artificial light. It can be seen from Column 2 and 3 that approximately this range of difference can be found in the natural light in one room, at different times of day, or in different positions in one room when window light is supplemented by artificial.

TABLE I

Error scores on 18 pseudo-isochromatic plates made by a sample of 27 applicants for submarine service under two illuminants. Percent of improvement is calculated as the difference of the scores divided by the number failed under Macbeth 6500° K.

Observer No.	No. of Plates Miscalled out of 18		% of Plates Miscalled out of 18		Percent of "Improvement"
	Under Macbeth 6500° K	Under Yellowish 2540° K	Under Macbeth 6500° K	Under Yellowish 2540° K	
Protanous					
1.	17	15	94	83	12
2.	16	16	89	89	0
3.	16	16	89	89	0
4.	15	15	83	83	0
5.	11	8	61	44	27
6.	9	5	50	28	44
Deutanous					
7.	18	7	100	39	61
8.	17	8	94	44	53
9.	16	9	89	50	44
10.	16	9	89	50	44
11.	16	8	89	44	50
12.	16	4	89	22	75
13.	15	10	83	55	33
14.	15	9	83	50	40
15.	14	7	78	39	50
16.	14	6	78	33	57
17.	13	7	72	39	46
18.	12	2	67	11	83
19.	12	2	67	11	83
20.	11	6	61	33	45
21.	11	4	61	22	63
22.	11	3	61	17	73
23.	11	3	61	17	73
24.	11	3	61	17	73
25.	10	1	56	6	90
26.	9	3	50	17	66
27.	8	4	44	22	50

Choice of Test Material:

A selection of plates can be made from the complete A.O. series which is statistically more reliable than the entire set[3,4,5,6]. The selection used in this study was the abridged group of 20 plates (2 demonstration, 18 diagnostic) which was chosen jointly by representatives of the Navy and of the Civil Aeronautics Authority and submitted to the Surgeon General. This selection includes most of the plates recommended in the Bureau of Standards Report and agrees in principle with previous selections by Griffiths, Weinbach, Sloan, Reed, Judd and the Royal Canadian Air Force. Inadequate as these plates admittedly are, they were chosen for test material because (1) they are in actual use in hundreds of recruiting stations (2) the above mentioned abridgement includes the majority of the most diagnostic plates and (3) there is little prospect of immediate substitution of a better test for general use in the Navy.

RESULTS

Each of the 27 applicants described in Report No. 3 of this series was given the abridged A.O. plates under the standard conditions recommended in the Bureau of Standards Report, with the standard illuminant, "Macbeth C"; and under the experimental test lamp "Room Y" which represented typical artificial illumination. The effect of the two illuminants on test scores is shown in Table 1. The table shows that the more severely protanous ("red-blind") observers were unable to "improve" their A.O. responses appreciably under yellow illumination. While the two mildest cases were evidently benefited, the size of the sample permits no precise determination as to ratio of degree of benefit to severity of defect. However, the "improvement" in the deutanous or "green-blind" observers, (numbers 7 to 27), was in no case less than 33%, reached as high as 90%, and averaged 60%. Fourteen of the 21 deutanous observers made less than half the errors under illuminant "Room Y" than they made under "Macbeth C".

Recommendations for interpretation of scores on the abridged test state, "subjects making 5 or more errors will be rejected for entry into the Naval Service." This criterion would reject all of the 27 applicants if the test were administered under standard illumination; if administered under average room illumination it would reject the 6 protanous applicants but would pass 10 of the 21 deutanous applicants. Mildly anomalous cases, who make 5, 6, or 7 errors, and would therefore "fail" the test under illuminant "C", were not included in this study. Mild cases easily pass the same test given under yellowish illumination, so if they had been included in the study it is evident that the above proportion would have been considerably increased.

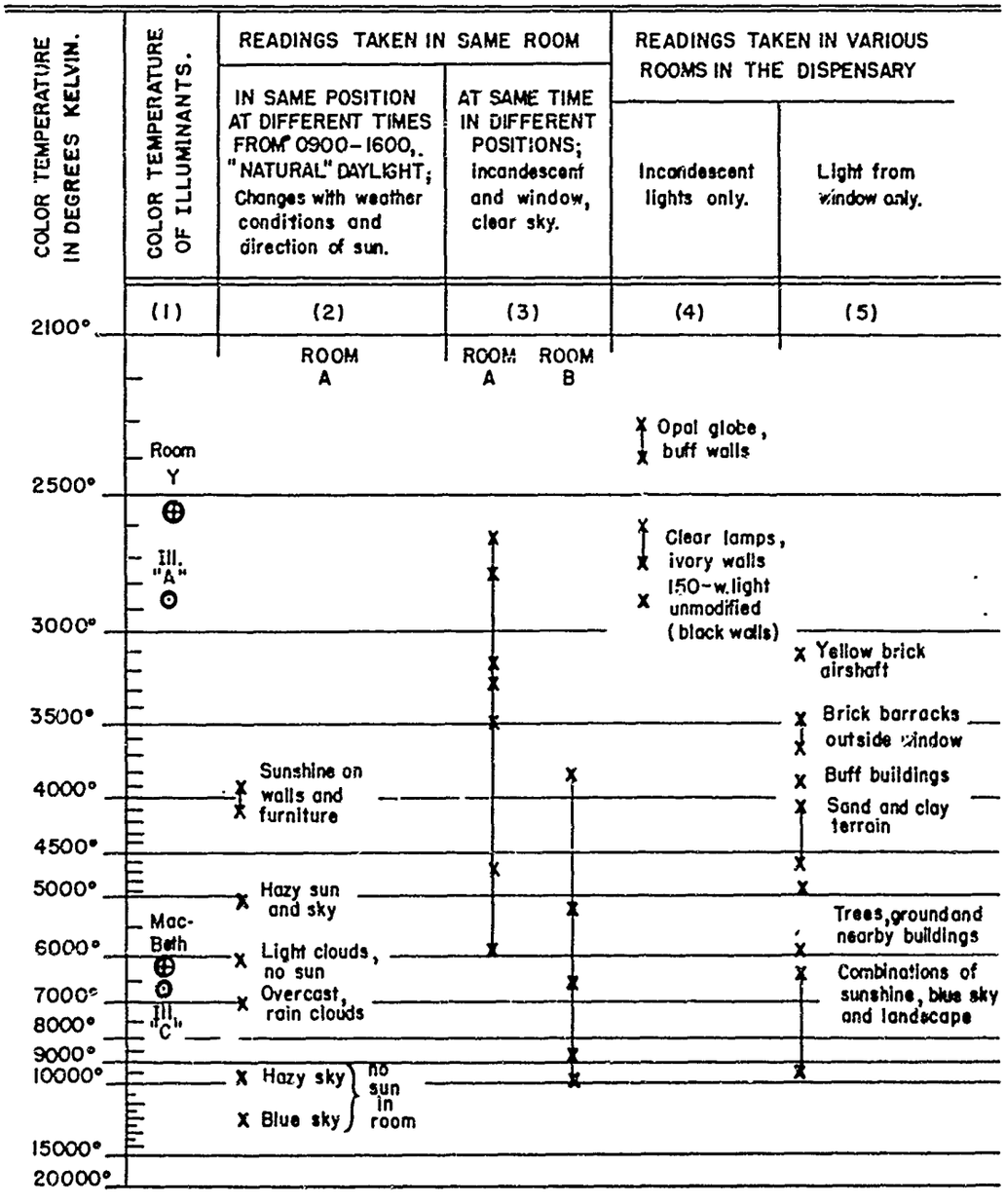

FIGURE 1.

Crosses Indicate Color Temperature Readings In Various Situations And Under Various Conditions.

This study furnished the explanation of a puzzling, if minor, problem in the services. It has been observed for a number of years that a disproportionately large number of "green-blind" men are found in the Navy and Air Corps and that an uncommonly large proportion of "red-blind" men are found in the Army. If pseudo-isochromatic tests have been generally administered under yellow lights in the Navy as Report 3 indicated, then it is evident that protanous men would make high error scores and be rejected, whereas deutanous men with the same degree of color defect would make fewer errors and more acceptable scores.

There are several general types of solution which have been suggested for this situation:

1. Standardization of the present plates under incandescent illumination, repetition of the statistical work on the selection and significance of plates and the setting up of separate "acceptance" criteria for deutanous and protanous. This would involve the addition of a test to determine the type of anomaly and to some extent the degree of anomaly. This is a cumbersome, inadequate and obviously impractical solution.

2. Use of a color temperature meter to determine when natural illumination approximates the standard, with test-administration restricted to these occasions. This is obviously impractical.

3. Creation of new test materials based upon a sound methodology for administration under 100-watt incandescent light. This may be desirable, but it is a long-term project.

4. Supply of a standard lamp with the test plates which furnishes average daylight illumination. This is a simple and practical stopgap by which regulations can be complied with and test results can be made as reliable as the present materials permit.

CONCLUSION

A pseudo-isochromatic test is in two parts; it is not a book of plates alone, but a combination of certain colors with certain light.

Yellowish (low color temperature) illumination such as incandescent light or light reflected from brick walls or yellowish bulkheads, is a decided aid to recognition of pseudo-isochromatic plates by deutanous observers. Criteria of rejection in terms of error scores are not, therefore, applicable to this class of color deficient. Yellowish illumination is of little aid to recognition of the figures by protanous observers. There is an apparent tendency for the mildly protanous to benefit by yellowish light more than those with more severe defect.

It can be concluded that when the A.O. Co. test for color perception is administered under yellowish, non-standard illumination, at least half the deutanous applicants would be acceptable by the same error score criterion by which they would fail under standard illumination; but that the errors of only the milder protanous applicants would be reduced.

It is strongly recommended that pseudo-isochromatic tests be given under standard illumination such as Macbeth Daylight lamp or other incandescent light which is color-corrected by suitable filters to approximate illuminant "C". If pseudo-isochromatic plates are to be continued in use for testing, they should be made up in a unit consisting of plates and illuminant. It would appear from reference[1] that an 18 inch fluorescent lamp of "Daylight" color may be a satisfactory substitute for the above named standard lights. However, there is so much variation in the color-temperature of fluorescent lamps, not only between new ones but with aging of individual lamps, that the subject would require further study before a recommendation could be made. The study should include the differential effect upon protanopes and deuteranopes.

An investigation should be made of the color relations underlying the illumination effects discussed in this report.

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